Review

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Rice Production in Ghana: A Multi-Dimensional Sustainable Approach

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Review

Rice Production in Ghana: A Multi-Dimensional Sustainable Approach

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Abstract: In Ghana, rice remains a critical crop, representing 15% of the country's GDP. However, production has been hindered by limited water access, degraded soil, pests and diseases, and ineffective pesticide use. These issues have impeded industry growth while adversely affecting the environment and impairing socioeconomic development. To combat these challenges, it is necessary to implement sustainable production strategies that emphasize environmental protection, resource management, and socioeconomic progress. This study evaluates sustainable rice production in Ghana, taking into account its consequences on the environment, socioeconomic growth, and food security. It pinpoints gaps and offers advice for stakeholders, policymakers, and scholars to transition to sustainability. The study illuminates the increasing significance of rice in Ghana and its role in food security, illustrating increased output due to widened land rather than higher yields. It underscores the necessity of fulfilling surging demand while implementing environmentally friendly practices. The paper scrutinizes the difficulties encountered by the rice sector, such as restricted water supplies and soil degradation, along with the adverse impacts of pests, diseases and inefficient pesticide utilization. Sustainable methods are imperative for Ghana's agribusiness, environmental protection, and socioeconomic progress. By embracing green techniques, prioritizing resource management, and investing in research, Ghana can surmount production issues. This review provides invaluable insight and suggestions for policymakers, academicians, and stakeholders alike to ensure sustainable rice production for current and future generations.

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1. Introduction

Rice is one of the most vital staple crops globally, providing sustenance to more than half of the world's population. In the Ghanaian economy, rice occupies a significant position as a strategic crop, acting as both a crucial food source and a crucial cash crop [1]. It is impossible to overstate the significance of rice to the Ghanaian economy, which accounts for about 15% of GDP [2]. In response to accelerating population expansion, rapid urbanization, and changes in consumer preferences, rice farming has assumed significant importance. It substantially contributes to improving household food security in Ghana and Africa, as it is the second most popular cereal staple after maize [3]. As shown in Table 1 paddy rice production increased from 302,000 to 987,000 MT from 2008 to 2020 respectively according to the Ministry of Food and Agriculture (MoFA) [4]. With Africa producing 14.60 million tons of rice during the past 50 years, the emphasis now needs to be on establishing sustainable production methods that put environmental preservation, resource management, and socioeconomic development first. Although more land has been cultivated for agriculture, there is still a need to address the growing demand for rice in a way that promotes sustainable farming methods over the long term. We can meet the rising demand for rice while protecting our natural resources and promoting socioeconomic development for the continent by using ecologically friendly and resource-efficient methods. [5]. The Ministry of Food and Agriculture has facilitated the revision of the National Rice Development Strategy (NRDS), intending to achieve self-sufficiency by 2024 [4].

Table 1. Rice Production Trends in Ghana.

Year	Paddy Rice Production (1000MT)	Milled rice production (1000 MT)	Rice consumption (1000 MT)	Rice self-sufficiency ratio (%)
2008	302	181	800	23
2019	963	665	1450	46
2020	987	622	-	43

Source: [4].

Ghana's rice production, as well as other African countries, faces several challenges. These challenges include limited access to water resources, soil degradation, pests and diseases, and suboptimal use of agrochemicals. These factors contribute to difficulties in achieving optimal rice yields and hinder the growth of the rice industry in Ghana and other African nations. Unsustainable farming practices such as tilling the soil, monocropping, deforestation and excessive use of chemical fertilizers not only contribute to environmental degradation but also hinder long-term productivity and socio-economic progress. These difficulties impede farm productivity and profitability [6]. Therefore, a shift towards sustainable rice production practices is essential for Ghana's agricultural sector, particularly in the rice industry. Additionally, doing so is vital to preserve the planet's already finite natural resources and ensure that there will be enough for current and future generations' needs. Furthermore, compared to outmoded conventional/unsustainable practices, embracing contemporary, sustainable scientific practices enable farmers to obtain increased yields in the face of climate change. The challenges and production trends in Ghana's rice business are insightfully illustrated in Figure 1 in a visual format. The main elements affecting the nation's rice output as well as the changes in paddy rice production through time can be better understood through this graphical summary.

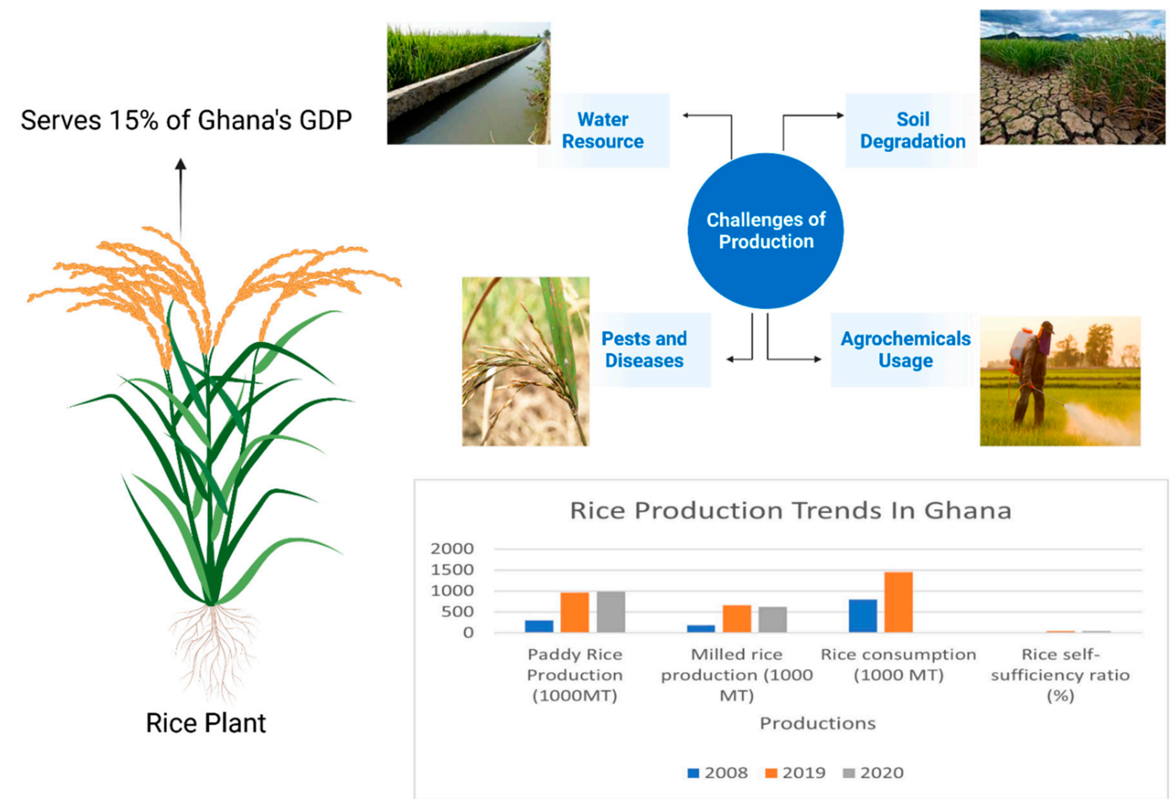

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Figure 1. Overview of Rice Challenges and Production Trends in Ghana.

This review examines the current state of sustainable rice production practices in Ghana, assessing their impact on environmental sustainability, socio-economic development, and food security. It also identifies the research gaps and outlines strategic directions for enhancing sustainable rice production in the country. Through this comprehensive analysis, we aim to provide valuable insights and recommendations for policymakers, researchers, and stakeholders to support the transition toward sustainable rice production systems in Ghana.

2. Sustainable Rice Production Practices in Ghana

2.1. Water Management

Irrigation production continues to be one method of boosting agricultural production in order to fulfill the growing worldwide need for food. Given how water-intensive rice growing is, water management represents a key component of sustainable rice production [7]. Effective water management techniques are essential to maximize water use and ensure the sustainability of rice production in Ghana, where access to water resources might be constrained [8]. To improve water and soil management and create effective irrigation systems, several water and soil conservation techniques for rice farming were created and put into operation [8]. In Ghana, rice is primarily produced in three (3) ecosystems. These are (i) rice fields that receive irrigation, (ii) lowland/hydromorphic rice fields, and (iii) highland rice fields. Seventy-five percent of the world's rice is produced by the irrigated lowland rice system, which covers around 93 million acres. Around 56% of the world's irrigated land is devoted to crops, with rice accounting for 40–46% [9].

2.1.1. The Alternate Wetting and Drying

The alternate wetting and drying (AWD) technique remains one method that has shown promise in lowering water consumption while maintaining or increasing yields [10]. The AWD technique uses a cyclical procedure, as shown in Figure 2, where the rice fields endure alternating wet and dry seasons. In order to ensure that the field is sufficiently immersed during the wet phase, water is slowly supplied to the rice paddies, either through controlled irrigation or direct flooding. The water is then gradually removed or allowed to evaporate, which results in a regulated drying process. The length of each wet and dry cycle might differ depending on the temperature, soil type, and stage of crop development, all of which are taken into account when optimizing the AWD method [11]. Farmers can avoid flooding their fields by utilizing a water control system to keep the soil moisture at a level that matches the crop's needs for water.

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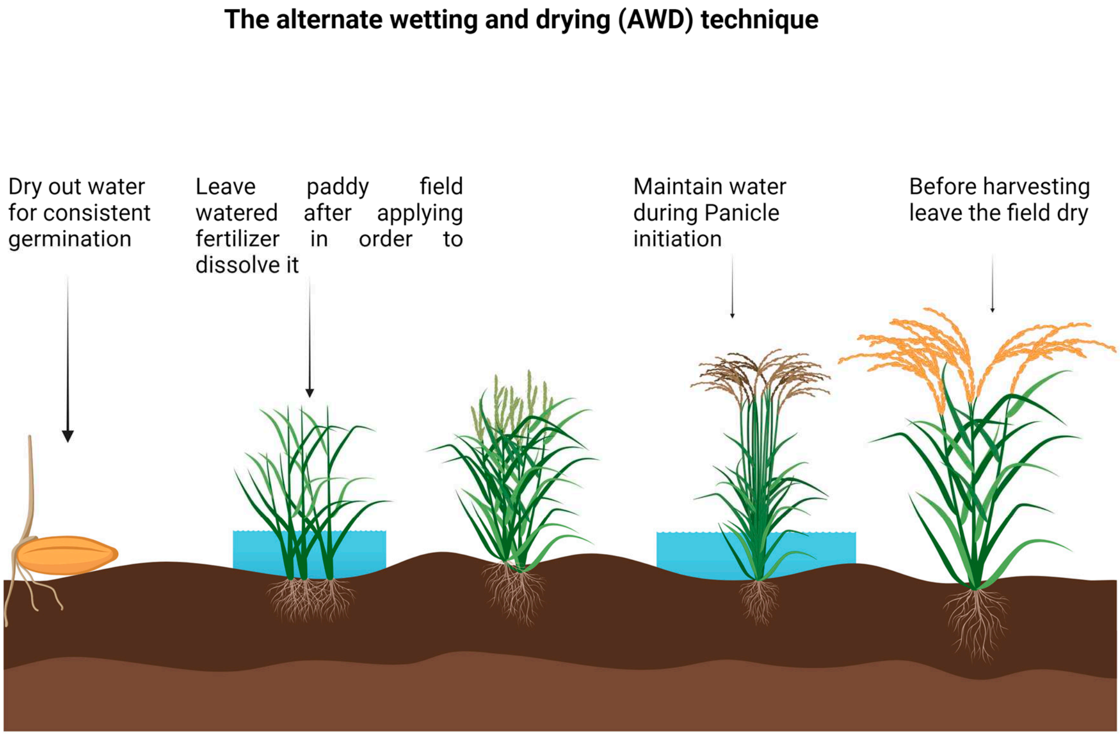

Figure 2. Illustration of the alternate wetting and drying (AWD) technique on a rice field.

In Ghana's Volta region, a study shows that AWD reduced water use by 20–30% compared to continuous flooding, with no appreciable difference in yield. [12]. Water use and the potential for global warming (GWP) have both been greatly reduced due to the implementation of AWD systems [13]. However, there are varying reports on how managing irrigation to prevent flooding in rice fields affects rice yield. Some studies indicate an increase in yield under the AWD system compared to the Continuously Flooded (CF) system, while others show a decrease. These conflicting findings highlight the need to optimize irrigation management based on factors such as soil properties, drainage frequency, flooding duration, and crop adaptability [13]. Table 2 demonstrates that AWD and Saturated Soil Culture (SSC) can produce yields comparable to or greater than CF while using less water, whereas Aerobic Rice (AR) can conserve more water but produce less yield. This indicates that AWD and (SSC) are more productive and water-efficient than CF, while (AR) is more productive but less water-efficient than CF. By combining water-saving production and irrigation systems, we can enhance water productivity, improve water efficiency, and achieve better economic returns while reducing the environmental impact (Global Warming Potential).

Table 2. Different irrigation systems and their water use efficiency and yield.

Irrigation system	Water-saving irrigation method	Water-conserving agronomic practice	Water use efficiency (WUE)	Yield (t/ha)
Irrigated lowland	Alternate wetting and drying (AWD)	Transplanting young seedlings at wider spacing	1.4 kg/m^3	5.7
Irrigated lowland	Saturated soil culture (SSC)	Transplanting young seedlings at wider spacing	1.3 kg/m^3	5.6

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Irrigated lowland	Continuous flooding (CF)	Transplanting older seedlings at closer spacing	0.9 kg/m^3	5.2
Irrigated lowland	Aerobic rice (AR)	Direct seeding of aerobic rice varieties	1.8 kg/m^3	3.2

Source: [14].

2.1.2. Precision Irrigation

Other water-saving solutions are being investigated for rice production in Ghana, in addition to AWD. Precision irrigation systems, such as drip irrigation and sprinkler irrigation, are one such technique. These technologies make it possible to precisely manage the amount of water applied, reduce water loss due to evaporation, and guarantee that water is delivered to the crop root zone [15]. Rice cultivation can benefit from drip or sprinkler irrigation systems to enhance the efficiency of water and fertilizer usage. The drip system has the potential to conserve water and other nutrients by allowing water to drip continually to the main roots of the plants and other plant parts that are located on the surface of the soil or buried under the surface of the soil. Putting water into the root zone and reducing water vapor are two basic goals of drip irrigation [16]. Drip irrigation, according to Parthasarathi, et al. [2018], boosted water productivity, favored root oxidizing power, canopy photosynthesis, and dry matter partitioning, improved aerobic rice yield by 29%, increased water saving efficiency by 50%, and increased water productivity. This is crucial because traditional flooding methods used in rice production consume more water compared to any other crop in agriculture [18]. Additionally, the use of water collection methods can increase the amount of available water for rice production during the dry season. This involves collecting and storing rainwater runoff from roofs and fields as well as creating small ponds or reservoirs to store water for irrigation. To conserve water and provide adequate watering, the drip irrigation system is very beneficial and essential. As the world's population grows every day, water shortages will become more and more of a concern in the future. Flooding wastes a lot of water, contributes to greenhouse gas emissions, releases methane, and pollutes aquifers [16]. An in-depth visual representation of a rice farm with sprinkler and drip irrigation systems integrated is provided in Figure 3. This cutting-edge farming setup seamlessly integrates contemporary water-saving measures to boost water efficiency and improve overall rice yield. The picture demonstrates how these precise irrigation systems can be strategically used to improve water distribution and satisfy the unique water needs of rice crops.

The sprinkler irrigation sprays water on the plant from above. They are more accessible and less expensive but they also produce more runoff and evaporation since they cover a broader area.

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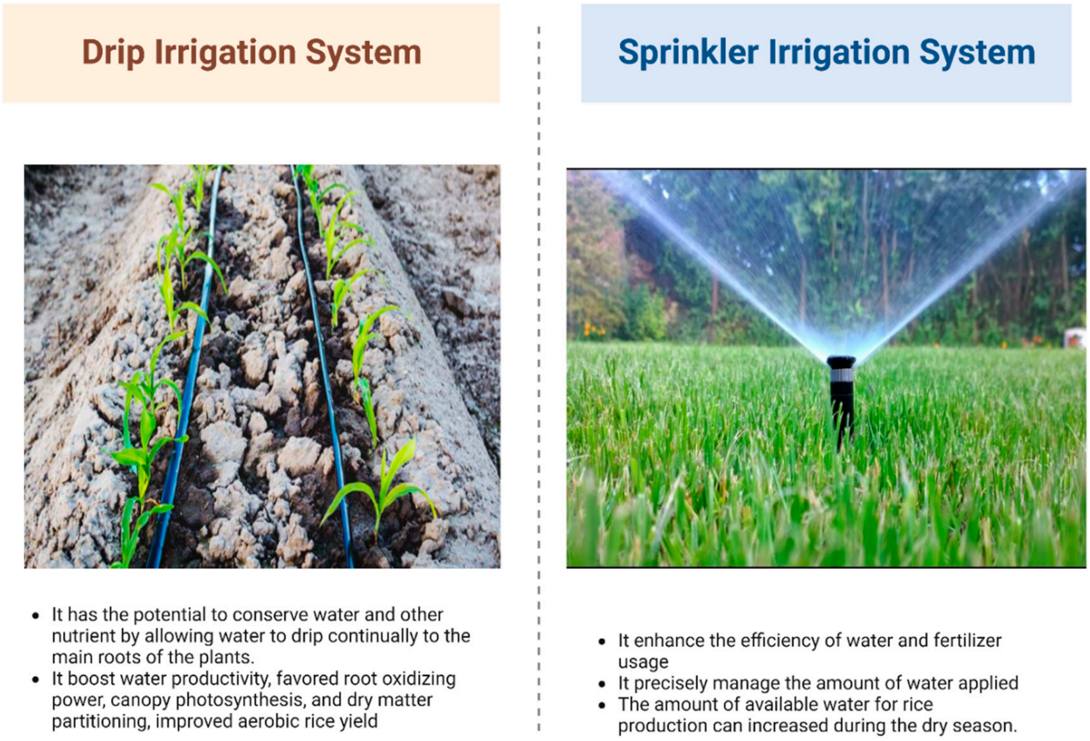

Figure 3. Overview of Rice farm with Drip and Sprinkler Irrigation.

Some methods contribute more to water conservation than others, according to Arouna, et al. [2023], who reviewed various methods used to estimate irrigation water requirements in irrigated rice production. The authors also looked at how water conservation technologies affected rice yields and water use efficiency and discovered that, in comparison to surface flooding, drip irrigation systems increased irrigation water productivity to 1.03 kg/m^3, reduced irrigation water use by 42%, and increased irrigation efficiency. These water management techniques could increase water productivity in rice production systems while also helping to conserve water. The term "water productivity" describes how much grain is produced for every unit of water used. Higher water productivity can be attained by putting water-efficient strategies into practice, ensuring the limited water resources are used effectively to boost rice yields [19]. The impact of AWD production system on rice grain quality in various nations is summarized in Table 3 based on previous research investigations. AWD can have different effects on rice grain quality in different geographic areas, emphasizing the necessity for region-specific measures for water management in rice agriculture.

Table 3. Alternate wetting and drying (AWD) production system's impact on rice grain quality in various countries.

Countries	Effect of AWD on Rice Grain	Reference
China	Severe AWD decreased grain quality while moderate AWD increased it.	[20]
	Increased grain pulpiness, decreased chalkiness, and improved head rice recovery, with no changes to amylose, protein, or gel consistency.	[21]
Japan	Better grains and Increased grain ripening ratio and protein concentrations were the result of prolonged moderate AWD.	[22,23]

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Iran	Increase in grain protein content and milling recovery under mild-AWD system	[24]
Bangladesh	Decrease in the concentration of grain sulphur, calcium, iron, and arsenic and increase in the concentration of grain Mn, Cu, and Cd	[25]
Philippines, India, Nepal, Bangladesh and Cambodia	Intermediate amylose contents, decrease in chalkiness, and increase in head rice recovery	[26]

2.2. Nutrient Management

Since nutrient management directly affects crop development, output, and environmental sustainability, it is a critical component of sustainable rice cultivation in Ghana [27]. The goal of good nutrient management techniques is to give rice plants a balanced and sufficient nourishment while reducing nutrient losses and environmental pollution [28]. After the green revolution, farmers started relying heavily on chemical fertilizers to increase rice production. Unfortunately, this excessive use of fertilizers has led to the deterioration of soil quality and has had negative effects on the ecosystem and biodiversity. Chemical fertilizers used extensively to intensify agriculture caused a major deterioration in the physicochemical characteristics of the soil [29]. Due to the application of long-term fertilizer in a range of crops, changes in Soil Organic Carbon (SOC), pH, nitrogen (N) content, moisture, and therefore the variance in nutrient availability to microbes have been noted [30,31]. The primary input for high-yielding rice farming worldwide is chemical fertilizer.

2.2.1. Essential Nutrients for Successful Rice Cultivation

The three nutrients that are most frequently used for rice cultivation are nitrogen (N), phosphorus (P), and potassium (K). About 15-20 kg of mineral N, 11 kg P2O5, 30 kg K2O, 3 kg S, 7 kg Ca, 3 kg Mg, 675 g Mn, 150 g Fe, 40 g Zn, 18 g Cu, 15 g B, 2 g Mo, and 52 kg Si are needed to produce one ton of raw rice [32]. The vital nutrient phosphorus plays a significant role in rice formation. It provides and transports energy during plant metabolism. Soil factors such as pH, phosphorus adsorption capacity, temperature, rice type, and management techniques influence phosphorus effectiveness in rice farming. Phosphorus remains less mobile in the soil system compared to nitrogen (N) and potassium (K), resulting in a substantial buildup of applied phosphorus in agricultural soils [33]. In acidic soils, complexes with iron (Fe), aluminum (Al), and in high pH soils, calcium (Ca) causes 75% to 90% of the phosphorus fertilizer to precipitate after application [34]. For various African countries, appropriate rice fertilizer dosages are shown in Table 4 for lowland, rainfed upland, and irrigated lowland rice ecologies. These dosage parameters are crucial for farmers to follow in order to guarantee that their rice crops receive an adequate quantity of nutrients while avoiding overfertilization that could cause environmental contamination.

Table 4. Some African nations' recommended rice fertilizer dosages.

Country	Rice ecology	Dosage	Reference
Ghana	Lowland	90N–26P–50K	[35]
	Rainfed Upland	90N–20P–30K	[36]
Nigeria	Lowland	60N–13P–25K	[37]
	Rainfed Upland	50N–30P–30K	[38]
Cote d'Ivoire	Irrigated Lowland	71N–20P–38K	[39]
	Rainfed upland	70N–21P–30K	[40]
Togo	Lowland	122N–13P–25K	[41]
	Rainfed Upland	45N–10P–19K	[42]

2.2.2. Optimized Fertilization Techniques

Nine commonly used optimized fertilization techniques are straw inclusion, delaying N application, formula fertilization, lowering fertilization, deep fertilization, slow/controlled released fertilizers, combined application of organic and inorganic fertilizers, adding biochar and green manure. Sustainable rice production greatly benefits from balanced fertilization techniques, it entails applying fertilizers at the proper times, in the proper volumes, and in the proper ratios [43]. A crucial technique for identifying nutrient imbalances or inadequacies and directing fertilizer recommendations is soil testing.

Straw Inclusion

When rice straw is incorporated, the amount of potassium (K), nitrogen (N), and phosphorus (P) that rice needs to grow can be reduced. Rice straw comprises around 80, 40, and 30% of the K, N, and P that rice needs to grow. Due to its poor decomposition, the timing of this operation, together with water management, becomes crucial [44]. It has been demonstrated that the in-situ integration of rice straw into the soil boosts soil organic carbon (C), aids in the recycling of nutrients, and increases crop yields in the future [45]. Schmidt, et al. [2015] noted that rice straw provides a substrate to promote biodiversity through the flourishing of invertebrates that decompose the straw, which in turn enhances nutrient cycling in paddy soils. In a study carried out in Vietnam by Thanh, et al. [2016], the addition of rice straw was demonstrated to enhance soil organic C, soil pH, and nutrient content in comparison to the starting conditions. Consistently incorporating crop residues into rice soils after every crop has the potential to enhance the nitrogen-supplying capability over time. A significant and easily accessible biomass in Ghana is crop straw. A visual example of the straw inclusion technique's practical application in freshly built rice beds is shown in Figure 4, which highlights the simple yet very successful method for improving nutrient management in rice production. In this illustration, farmers carefully place rice straw into the soil of newly constructed rice beds, as it has considerable potential for sustainable rice cultivation. However, due to the existing use of traditional methods of exploitation, crop straw is underutilized in Ghana [48].

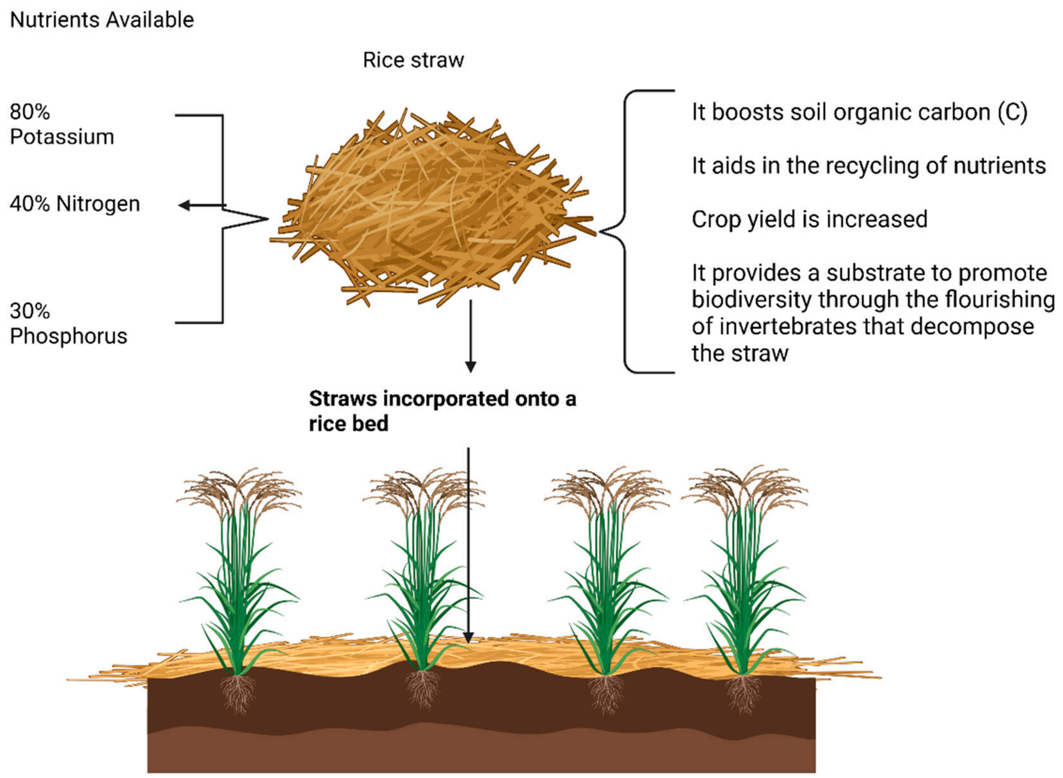

Figure 4. Straws incorporated into newly constructed rice bed.

Delaying N application

Reducing N fertilizer application on the grounds of maintaining crop output has become a common necessity for sustainable agriculture due to the rise in consumer knowledge of the safety of agricultural products and environmental protection [49]. Adjusting the timing and rate of nitrogen (N) delivery is one possible agricultural approach for improving nitrogen usage efficiency (NUE) in rice farming [50]. Farmers can lower the total quantity of N needed during the basal stage by delaying N application. Instead, higher amounts of fertilizer can be administered when the rice plants are in the tillering and booting stages since they are more responsive to nitrogen uptake at those times. This strategy promises to increase rice output while at the same time lowering N losses in addition to improving NUE. Moreover, growers may be able to reduce labor input, expediting the cultivation process, by improving N application procedures [51].

Formula Fertilization

Utilizing formula fertilization, which involves calculating the optimal rate and ratio of nitrogen (N), phosphorous (P), and potassium (K) fertilizers based on extensive soil testing, is essential for maximizing fertilizer application in rice farming [52]. Farmers can customize their fertilizer routine by doing thorough soil analysis to gain useful insights into the nutrient content and pH levels of the soil [53]. This method has the potential to increase rice yield while simultaneously improving NUE. Also, it is possible to decrease fertilizer applications by precisely estimating the soil's nutrient needs, which lowers costs and the environmental impact of excessive fertilizer use. The necessity of effective nutrient management in rice has increased since it not only ensures high levels of rice production but also minimizes the amount of applied nutrients that leak into the environment [54].

Lowering Fertilization

Reducing nitrogen (N) fertilizer application rates by 10–30% based on existing fertilizer application rates and the unique needs of the crop is a viable technique to reduce the environmental impact of excessive fertilizer usage in agriculture [55]. This strategy allows farmers to meet the nutrient needs of the crops while greatly reducing their total dependency on chemical fertilizers [56]. To maintain grain yield, improve nitrogen usage efficiency, and lessen environmental impact, nitrogen fertilizer use must be reduced [57]. This decrease in fertilizer use not only promotes more environmentally friendly farming practices but also minimizes nitrogen losses [58]. Farmers can strike a balance between preserving crop yield and minimizing the potential negative effects associated with excessive fertilizer use by implementing appropriate and accurate nutrient management strategies [59].

Deep Fertilization

Applying chemical fertilizer below the soil's surface, often at a depth of between 6 and 10 cm, is known as "deep fertilization." This method has several potential advantages for growing rice. Deep fertilizer placement offers the ability to overcome conservation tillage's productivity restriction and widespread adoption [60]. The method of side-deep fertilization is crucial to the sustainable growth of rice crops [61]. By bringing the fertilizer (nitrogen) closer to the root zone, where it can be more easily absorbed by the plants, it increase NUE [62]. This focused application increases the use of nitrogen while decreasing losses and improving nutrient uptake efficiency [63]. Deep fertilization as shown in Figure 5 involves the precise and meticulous application of fertilizer below the soil surface to maximize the availability of nutrient to rice plant. Farmers employ specialized equipment to carefully distribute the chemical fertilizer at the desired depth, which is normally between 6 and 10 cm below the soil surface.

Additionally, deep fertilization may increase rice yield by ensuring a consistent and ample supply of nutrients throughout the growing season. [64]. Reports by Hong, et al. [2023], stated that under standard rice and soybean cultivation circumstances, deep fertilization will be an efficient fertilizer application technique utilized to boost rice and soybean yields. This approach also

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encourages the development of deep roots, allowing plants to obtain water and nutrients from deeper soil layers. Deep fertilization of rice boosted tillers and panicle rates, increased yield, reduced labor costs, avoided delayed senescence, and managed diseases and insects as well as raised fertilizer consumption by 25% [66]. Deep fertilization can encourage lively plant growth and development by raising the amount of nitrogen that is available in the root zone. [67]. Farmers can improve nutrient management, improve crop performance, and promote sustainable rice production by embracing deep fertilization techniques.

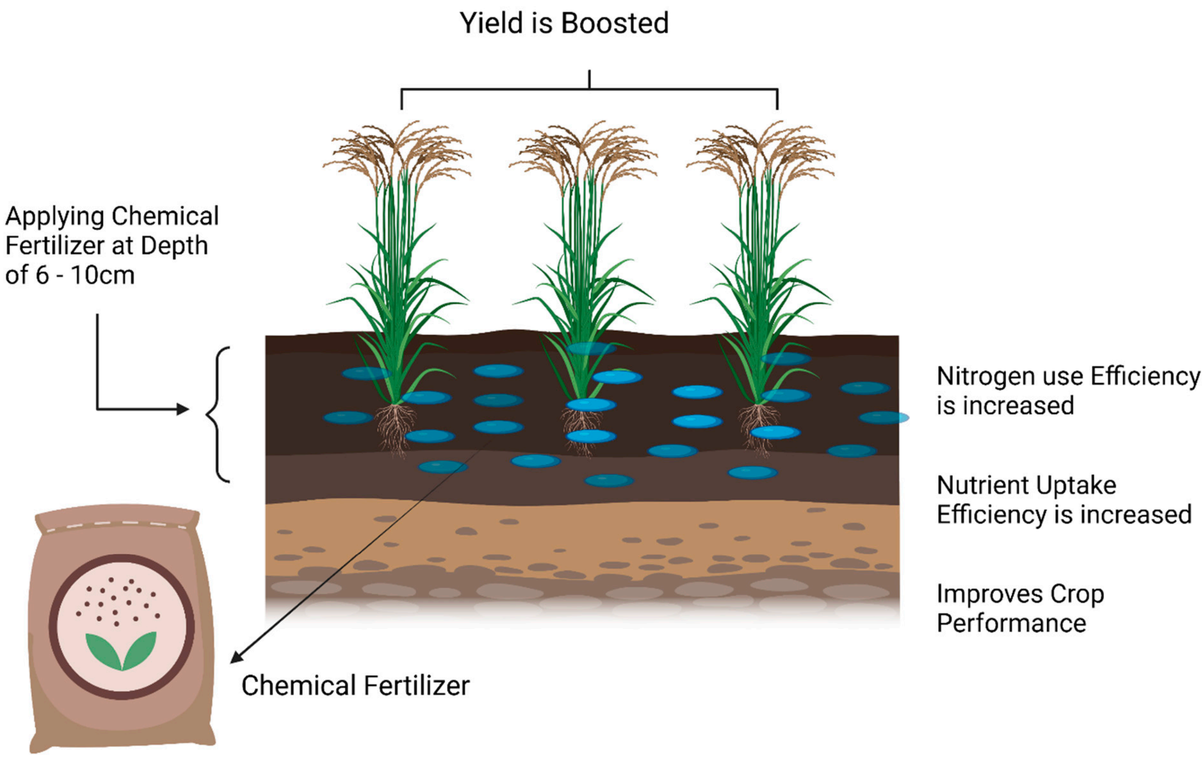

Figure 5. Deep Fertilization in Rice Farm.

Slow/Controlled Released Fertilizers

Specialized fertilizers known as slow/controlled-release fertilizers are made by encapsulating mineral fertilizers inside of a synthetic polymer matrix or by covering them with a polymer film [68]. In agriculture, this novel strategy has many positive effects on crops and grain yield [69]. Slow-release controlled fertilizers boost crop yields by gradually preserving the soil's health [70]. Firstly, by allowing for a controlled release of nitrogen, these fertilizers give plants a steady supply of nutrients over an extended time [71]. This regulated release method optimizes nutrient uptake, lowers the chance of nutrient runoff or leaching, and hence lessens the total demand for chemical fertilizer applications [72]. The use of slow/controlled-release fertilizers also streamline field operations because they do not need to be applied frequently, saving farmers' work and time. Furthermore, by fertilizing less frequently, these fertilizers can help bring down the price of agriculture and also reduce environmental impact [59].

Combined Application of Organic and Inorganic Fertilizers

It is necessary to partially replace chemical fertilizers with organic resources, such as manure, when applying organic and inorganic fertilizers together [56]. Agriculture benefits significantly from this integrated approach in many ways. In the beginning, the addition of organic materials improves soil fertility by supplying a variety of nutrients and organic matter [73,74]. These organic inputs increase the soil's structure, ability to hold nutrients, and microbial activity, all of which are beneficial for the health of the entire soil [73]. According to studies by Nyalemegbe, et al. [2010], both cow dung and urea gave a paddy yield of 4.7t ha^{-1}. Moreover, studies by Jinwei and Lianren [2011] found that the combined application of large amounts of organic manure and inorganic fertilizers (A1B5) treatment enhanced field moisture capacity and organic matter the fastest; organic matter increased by 3.33 g kg1 and field moisture capacity increased by 11.25% from the start of the trial. The growing production range under the same fertilization was greater for the combined application of organic and inorganic fertilizers than it was for the individual chemical fertilizers, which ranged from 0.8% to 9.4%. The findings demonstrated the highest productivity contribution to the fertility of black soil was made by combining the application of organic and inorganic fertilizers. The soil fertility was improved, and it was the optimum fertilization arrangement for raising productivity levels. In intensive agricultural systems, soil acidity is a problem that can be solved by applying both organic and inorganic fertilizers at the same time. The pH balance of the soil can be adjusted by adding organic materials, creating a more hospitable environment for plant development [76].

Biochar Incorporation

Biochar is a solid byproduct created when biological organic materials are pyrolyzed in an anaerobic or hypoxic atmosphere [77]. It is added to agricultural fields. The cultivation of rice can profit greatly from this method. In the beginning, adding biochar improves soil fertility by supplying it with organic carbon and crucial nutrients. Biochar's porous nature encourages microbial activity and nutrient retention, which improves the health and fertility of the soil [78]. Additionally, research has demonstrated that adding biochar can boost rice yield by improving nutrient availability and encouraging root development [79]. Abukari [2019], asserts that an increase in the rate of biochar application at 4 Water Absorbing Polymers (WAP) led to an increase in soil moisture content. Also, field experiments revealed that adding biochar to upland rice paddies improved the soil's water permeability and water retention capacity. [80]. MacCarthy, et al. [2020] who experimented on biochar in Ghana found out that the topsoil's ability to store soil organic carbon was increased by the application of biochar. The effects of applying biochar and nitrogen fertilizer together on yield parameters were considerable. By considerably increasing root volume and nutrient (N, P, and K) uptake, biochar was introduced. This led to an increase in grain and straw yield. In 14 out of 16 cases (cropping cycles N rates), grain yields on plots altered with biochar were higher than those on plots amended alone with fertilizer. Between 12 and 29% more grain was produced across all N rates.

In addition, biochar enhances the soil's physical and chemical characteristics, including its potential to retain more water, which helps keep the soil moist during times of water stress [82]. Also, Atkinson, et al. [2010] stated that significant increases in plant productivity have been attained depending on the amount of biochar added to the soil, however, these claims come primarily from research in the tropics. Furthermore, biochar has the ability to reduce soil acidification by promoting a more balanced soil pH and creating a conducive environment for plant growth [84]. Farmers can improve soil quality, boost crop output, and support sustainable rice production. Farmers can improve soil quality, boost crop output, and support sustainable rice production. In order to improve soil fertility and promote sustainable rice production, biochar is strategically incorporated into the rice-growing process as seen in Figure 6, which gives a thorough visual representation of the process.

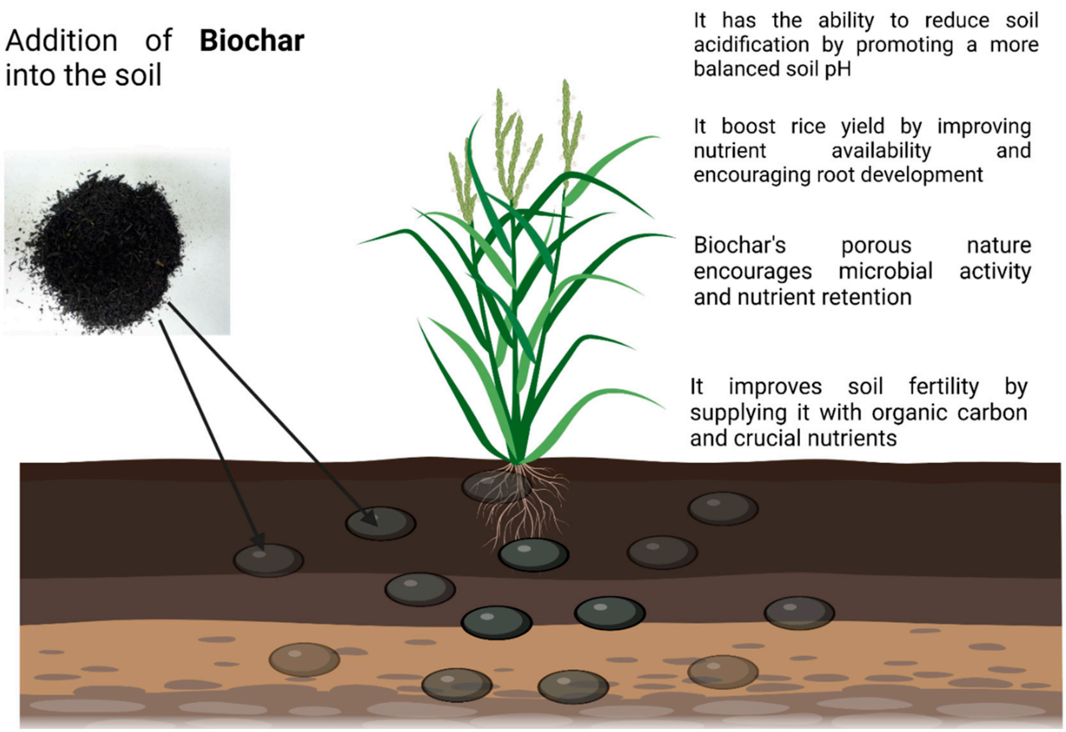

Figure 6. Illustration of Adding Biochar to the Soil.

Green Manuring

Green manuring is a technique in which green plant matter, also known as green manure, is integrated into the soil via plowing [85] as shown in Figure 7. The cultivation of rice can benefit from this method in several ways. Firstly, green manuring increases soil fertility by enhancing it with organic matter, which provides plants with nutrients. This was supported by research done by Latt, et al. [2009], that examined the effects of applying S. rostrata green manure on rice yield and growth. Treatments with urea (40 and 80 kg N ha -1) and no application were contrasted with green manure (2 and 4 plants pot -1) treatments. In comparison to urea and no application treatments, green manure treatments considerably enhanced the dry matter weight and grain weight of rice. The plant's intake of N increased with each application of green manure. It may be concluded that adding green manure legumes can significantly increase the quantity of biologically fixed nitrogen (N) in rice soils. As the green manure breaks down, vital nutrients are released into the soil, increasing its fertility overall [87]. Incorporating green manure has been shown to boost rice output in studies [88]. Additionally, this technique lessens the need for chemical fertilizers because green manure's organic matter acts as a natural supply of nutrients, encouraging the use of more sustainable farming techniques [89]. Also, Zhou, et al. [2020], discovered that adding green manure enhanced rice yield by 4.1%. By boosting aggregation, moisture retention, and nutrient-holding ability, green manuring also helps to improve the structure and characteristics of the soil. Additionally, it aids in modifying soil pH levels because some green manure crops can lessen soil acidity [90]. Overall, green manuring is a successful strategy for improving soil fertility, crop yield, lowering chemical inputs, and enhancing overall soil health in rice farming. The transformational effects of using green manure encompasses enhance rice yield, enhanced dry matter, enhance microbial activity Improve soil health and increase biomass (Figure 7) in rice production are effectively illustrated. Green plant matter can be successfully incorporated into the soil to reap its many advantages.

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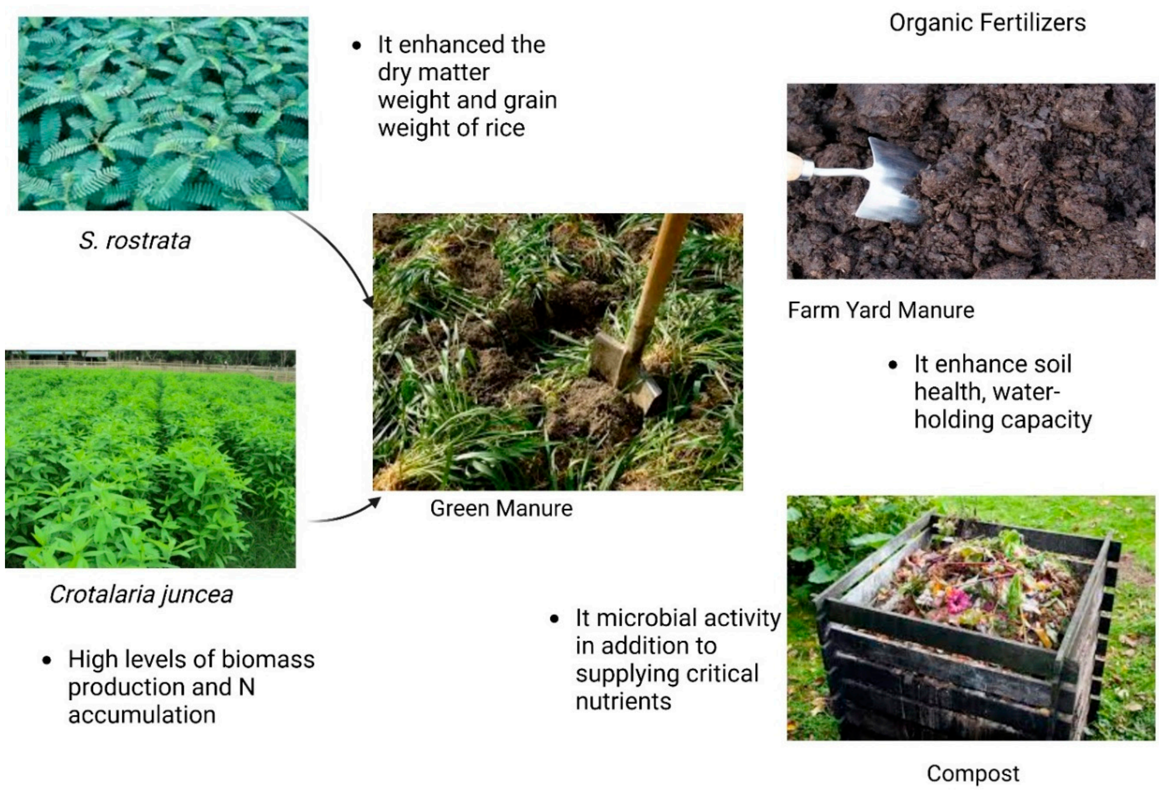

Figure 7. Picture of Green Manuring to Rice field.

After the demand for increased yields, environmental protection has become a key factor in promoting the adoption of optimal fertilization procedures. Most techniques often resulted in yield increases of more than 5% and TN loss reductions of more than 15% [51].

By tailoring fertilizer applications to the specific nutrient requirements of the soil and crop, farmers can increase the efficiency of nutrient usage while reducing the risk of nutrient runoff into water bodies [91]. In addition to chemical fertilizers, composting and the use of organic fertilizers are growing in popularity as sustainable rice production techniques. Examples of organic fertilizers that enhance soil fertility, soil structure, and promote nutrient cycling include compost, green manure, and farmyard manure [92]. These organic additions enhance soil health, water-holding capacity, and microbial activity in addition to supplying critical nutrients [93]

Another strategy that is becoming more popular in the development of sustainably grown rice is site-specific nutrient management (SSNM). In SSNM, the nutritional requirements of rice plants are determined at various growth stages, and the appropriate targeted nutrient treatments are made [94]. Rodriguez [2020], claims that this technique reduces nutrient losses, improves fertilizer usage efficiency, and minimizes environmental consequences.

Additionally, using soil additions like lime and gypsum can help balance out nutrient deficiencies and restore soil pH. According to Fageria and Knupp [2014], these treatments optimize nutrient uptake efficiency while increasing the availability of nutrients to rice plants. Farmers can also utilize precision nutrient management methods like fertigation (the application of fertilizers through irrigation systems) and foliar nutrient sprays to increase nutrient uptake and decrease losses. [97].

3. Integrated Pest Management

Integrating pest and disease management, which aims to lessen reliance on chemical pesticides while effectively eradicating pests and diseases, is essential for maintaining sustainable rice production [98,99]. Excessive pesticide use causes the destruction of beneficial insects and the outbreak of the pest [100,101]. Many regions of the world have identified herbicide resistance as a significant barrier to rice production. Hundreds of weed species are resistant to the main classes of herbicides, and many species are resistant to multiple herbicide classes [102]. Utilizing a combination of cultural, biological, and chemical control measures as part of integrated pest management (IPM) strategies results in a strategy that is both ecologically and economically sustainable.

3.1. Crop Rotation

IPM in the production of rice is built on cultural customs. Crop rotation is one of these strategies, which entails alternating the growing of rice with other crops in order to disrupt the life cycles of pests and decrease their numbers [103]. Reducing the amount of fertilizer used, cultivating many kinds or lines on a single plot, switching nursery locations, and taking phytosanitary precautions can all help avoid the spread of virulent virus strains to another rice-producing zone [104]. Furthermore, effective soil preparation methods like field leveling and the removal of weed hosts make it difficult for diseases and pests to spread and thrive [105].

3.2. Biological Control Techniques

Chemical pesticides can be replaced with sustainable biological control techniques. Biological control reduces pest populations by utilizing natural enemies of pests such as parasitoids, and predators [106]. For example, the introduction of predatory insects in rice fields, such as spiders and beetles, can successfully reduce pest populations [107]. The biological method of pest control broadly speaking also includes the use of pheromones for pest population monitoring and to prevent pests from breeding, sterilizing insects before releasing them, and using bio-pesticides, which are made from living creatures or the byproduct of living organisms [108]. The growth, feeding, and productivity of rice leaf folder larvae are impacted by some biological pesticides used in rice, such as Neem seed kernel extract (*Azadirachta indica A. Juss*), Vitex negundo L. leaf extract, and *Bacillus thuringiensis* [109]. These studies demonstrate the usage of natural plant products containing bacterial toxins inhibits growth, has an antifeedant impact, and maybe even has poisonous effects on dangerous insects.

IPM includes the prudent application of chemical pesticides when other control strategies are ineffective. To prioritize the selective use of target-specific pesticides, one must consider their effectiveness, influence on the environment, and potential risk to non-target organisms [110]. Therefore, farmers must be able to benefit from the ecosystem's diversity and production, and pesticide use must be based on ecological principles. Farmers must be aware of how to maximize the ecosystem's long-term productivity in the rice fields. The application of pesticides can be maximized, reducing pesticide residues and environmental concerns, by adhering to optimum time and dose, led by pest monitoring and forecasting systems [111]. By allowing for early detection and intervention, routine scouting and monitoring of rice fields are essential to effective pest and disease control. Farmers can avoid infestation growth and potential crop losses by responding quickly to pest and disease outbreaks [112]

4. Improved Rice Seed

Moreover, the cultivation of rice strains resistant to disease makes a substantial contribution to long-term pest and disease control [113]. In order to reduce the usage of chemical pesticides, breeding projects in Ghana have concentrated on creating rice types that display resistance to serious diseases including blast and sheath blight. Consequently, the adoption of resistant varieties represents a safer and more environmentally friendly alternative to heavy pesticide use in rice production. To develop insect-resistant rice crop varieties, various techniques have been employed. These include mutagenesis, which involves inducing mutations in the plant's genetic material, as well as the introduction of foreign genes through approaches like single-gene insertion or gene pyramiding. Additionally, transplastomic methods, genetically engineered or modified Bt toxins, oligonucleotide-directed mutagenesis, engineered nucleases, engineered plant membrane transporters, and antisense

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technologies have been utilized [114]. A higher grain production, improved crop growth, and a decrease in weed, insect, and disease damage were all benefits of using improved rice seeds [115].

5. Soil Health

To encourage sustainable rice production in Ghana, soil conservation techniques are crucial. It is essential to implement practices that not only increase output but also protect the long-term health and fertility of the soil due to the country's expanding population and the pressing need for food security. Ghana can achieve sustainable rice production and maintain the welfare of both the environment and its people by putting into place efficient soil conservation methods. Sánchez [2010], stated that with the right management of the soil environment, fertilizer use, and appropriate crop varieties, crop yields in Africa might be tripled. Conservation tillage is one of the main techniques used in sustainable rice cultivation. With this strategy, plowing and tilling—which can cause soil erosion and degradation—are reduced or completely avoided. Instead, no-till or minimal-tillage farming methods are used to preserve organic matter and reduce soil compaction. Conservation tillage enhances water infiltration and nutrient retention by maintaining soil structure, thereby improving the soil's general health [117]. According to Bandyopadhyay, et al. [2016] zero-tillage transplanting and zero-tillage direct seeding in rice are conservation tillage techniques anticipated to enhance crop water use efficiency and soil hydrology.

5.1. Soil Conversation

Rice farmers in Ghana also use crop rotation as a crucial method of soil conservation. Farmers can disrupt the cycles of pests and diseases, encourage the cycling of nutrients, and lessen soil degradation by diversifying the crops they cultivate in a single location. Rice cultivation is alternated with the growing of legumes or vegetables, which improves soil fertility and promotes environmentally friendly farming methods. It has been demonstrated by HE, et al. [2016] that crop rotation can improve soil quality, such as nutrition status and physical structure, by removing soil-borne diseases, pests, and weed reservoirs that cannot be effectively controlled by pesticides. A rice-maize rotation system might boost rice output by 10.5% and maize yield by 11.3% compared to continuous rice cropping, according to Hameed, et al. [2023], who studies the impact of cropping systems on yield and socioeconomic benefits of rice cultivation in Ghana. A rice-maize rotation method might boost net revenue by 16.7% over continuous rice cultivation, according to the study. Moreover, the studies done by He, et al. [2021], realized that in comparison to successive cropping of rice (RR), the yield, profit, and profit margin of PR (potato rice rotation), FR (fallow followed by rice), and WR (watermelon rice rotation) were all higher (Table 5). The PR cropping system produced the highest yield, profit, and profit margin when compared to the other three cropping systems. FR came in second, and RR fared the worst. The rice yield from PR was marginally greater than that from FW but significantly higher (p 0.05) than that from RR and WR (Table 5). Furthermore, PR generated much more revenue than any other farming system.

Table 5. Effect of cropping systems on yield and socioeconomic benefits of rice production.

Cropping System	Yield t/ha	Harvest Index %	Profit US Dollar/ha	Profit Margin %
RR	5.2 b	42.2 a	162 c	8.5 c
FR	6.1 ab	45.1 a	465 b	24.4 b
PR	7.1 a	42.8 a	826 a	43.4 a
WR	5.9 b	45.8 a	385 b	20.2 b

Note: The different letters following the values in a column indicate a significant difference ($p < 0.05$). The same letter means it is not significantly different. RR = successive cropping of rice; FR = fallow followed by rice; PR = potato rice rotation; WR = watermelon rice rotation. [121].

5.2. Integration of Agroforestry and Terracing

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Additionally, gaining ground in Ghana is the integration of agroforestry systems with rice farming. The development of a sustainable rice-based agroforestry technique can increase the productivity of inland valleys. Planting trees next to rice fields is known as agroforestry, and it has several advantages for preserving soil [122]. With the help of this technology, crops and trees can coexist in one field, which has the potential to improve soil fertility, boost biodiversity, and raise crop yields, among other advantages [122]. The organic matter content of the soil is increased by trees' leaf litter, which also reduces evaporation and soil warmth. This improves the water-retention ability, fertility, and soil structure [123]. In addition to helping to preserve the soil, agroforestry practices also promote biodiversity and improve the sustainability of the agricultural landscape [124].. In regions with few resources and where conventional agricultural methods have caused soil degradation and low yield, this strategy can be especially effective

Terracing is used in sloppy regions to prevent soil erosion and retain rainwater. Terraces, which are built like steps, minimize runoff and allow water to seep into the ground, keeping critical topsoil from being carried away. In Ghana's hilly regions, terracing is a practical way to maintain the quality of the soil, stop erosion, and guarantee the sustainability of rice production. Numerous approaches exist for terracing to improve erosion control effectiveness. First, terracing reduces the velocity and overall amount of runoff, weakening erosive effects Second, to stop soil erosion, terraced fields frequently have features like upslope contour hedgerows, vegetative filter strips, and grass barriers [125]. In a study by Sukristiyonubowo [2007], for sustainable rice cultivation in terraced paddy field systems, the application rates of urea and KCl combined with 33% of the rice straw produced in the prior growing season are strongly advised. Terracing in rice production facilitates soil carbon and nitrogen stocks [127]. Figure 8 shows a terrace in section. Cut-and-fill regions are used to create terraces. Filling up gaps enables the arable land to be increased, allowing for the large-scale cultivation of rice in steep terrain. In order to prevent runoff and field water, the ridges or embankments are crucial.

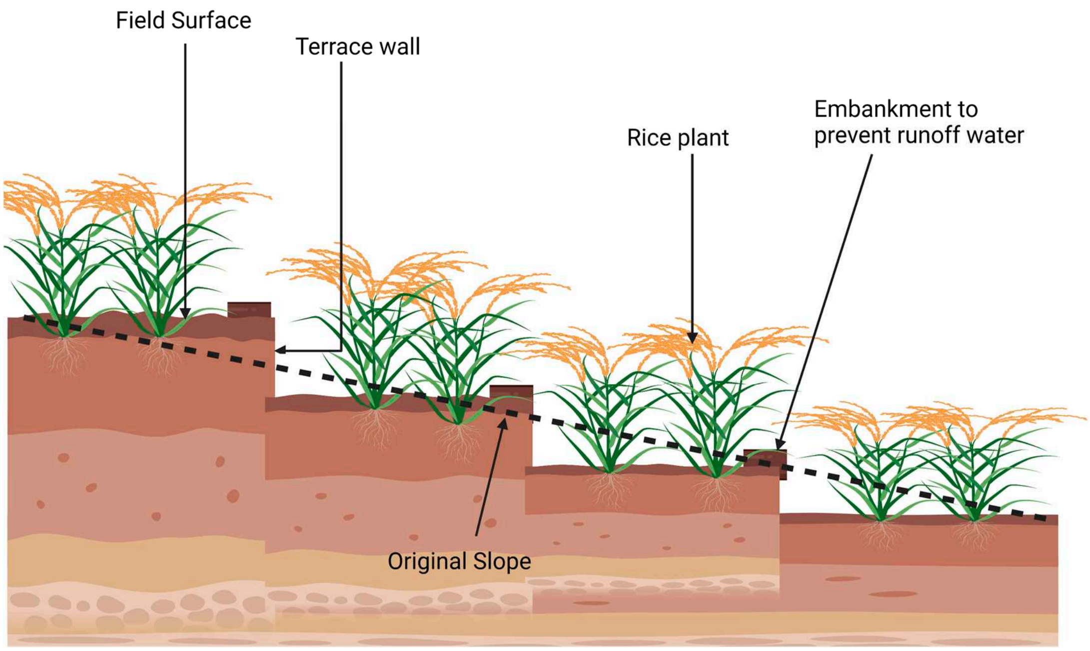

Figure 8. Sectional drawing of a terrace.

5.3. Use of Cover Crops

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Another important technique for conserving the soil used in the sustainable production of rice is the use of cover crops [128]. Farmers use cover crops like legumes or grasses during fallow times or in between rice harvests. These cover crops enhance soil structure, boost organic matter content, provide natural weed suppression, and protect the soil from erosion and nutrient leaching [128]. Cover crops promote environmentally friendly farming methods and improve the health and fertility of the soil by minimizing the need for herbicides. Ghana can encourage sustainable rice cultivation that reaps several benefits by putting these soil conservation techniques into practice. These techniques not only improve crop output, soil fertility, and water management, but they also lessen the total environmental effects of agriculture [129]. Food security for Ghana's population is ensured by sustainable rice production, which also protects the environment for future generations.

6. Conservation of beneficial insects and pollinators

Compared to other crops, rice fields are transitory wetlands that exhibit rapid physical, chemical, and biological changes as well as a higher diversity of organisms, particularly arthropods [130,131]. Arthropods, which are found in these ecosystems in an intermediate position in the food chain and include herbivores, saprophytes, parasites, and predators of other animals. These organisms are essential for maintaining ecological harmony, improving crop pollination, and acting as a natural pest control [131]. To preserve biodiversity, boost crop yields, and decrease the use of chemical pesticides, it is crucial to protect beneficial insects and pollinators [132]. However, few studies have shown how the diversity and quantity of natural enemies, such as parasitoids and predators, aid in biological arthropod pest management during various stages of rice crop development [133,134]. Within a specific range, agricultural productivity and biodiversity in agroecosystems are positively correlated, meaning that as biodiversity rises, so does production [135,136]. The opposite is also true; as biodiversity declines, so does agricultural output. The fact that it can successfully reduce the quantity of insect pests is one of the key justifications [137]. Statistics show that by reducing the biodiversity of agroecosystems, the number of plant eaters has increased by 18% while the number of plant eaters has decreased by 53% [130]. Information on several insect species that damage rice crops and the parasitoids that attack them is summarize in Table 6. Natural enemies such as these parasitoids aid in reducing the number of pests in rice crops. They are members of several insect groups, demonstrating the variety of beneficial creatures that are essential to preserving ecological harmony and controlling pests in rice habitat. The food chain for herbivores and their natural enemies is built around arable weeds. Furthermore, a variety of helpful insect species, particularly crop pollinators, are supported by arable weeds [138].

Table 6. Various rice insect pests and their parasitoids.

Insect order	Insects	Parasitoids	Reference
Araneae	Leaf- and planthoppers	Hunting spiders (Lycosa)	[139]
Coleoptera	Blister beetles	Coccinellidae (predatory beetles)	[140]
Coleoptera	Leaf beetles	Coccinellidae (predatory beetles)	[141]
Coleoptera	Stem borers	Tiger beetles (Cicindellidae), Ground beetles (Carabidae), Hydrophilidae (Hydrophilus acuminatus larvae)	[142,143],
Diptera	Stalk-eyed flies	Tomosvaryella spp., tachinid flies	[144]
Hemiptera	Green leafhoppers	Mirid bug (Cyrtorhinus lividipennis)	[145]

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Hymenoptera	Brown planthopper eggs	Mymarids, trichogrammatids, eulophids	[146]
Hymenoptera	Stem borer larvae and pupae	Braconids, elasmids	[147]
Neuroptera	Green lacewing	Aphid lions (larval form)	[148]

7. Conclusion and Future Prospect

The significance of sustainable rice production practices in Ghana and their consequences for the environment, socioeconomic development, and food security are highlighted in this review paper's conclusion. It lists the main difficulties the rice industry faces, including the inability to acquire enough water, soil degradation, pests, diseases, and inadequate pesticide application. These difficulties have prevented the industry's expansion and negatively impacted Ghana's socioeconomic and environmental developments. The analysis highlights the growing significance of rice in Ghana, where it contributes significantly to the GDP and is essential to guaranteeing food security. It is important to understand, nevertheless, that boosting rice production just by enlarging the amount of farmed area is not a long-term answer. Instead, implementing resource management strategies and ecologically friendly behaviors is crucial. The National Rice Development Strategy, which seeks to achieve self-sufficiency in the production of rice by 2024, is one example of the Ghanaian government's dedication, which is underlined by the study. This dedication offers a strong framework for the adoption of sustainable production methods. The review study underlines the need to adopt green practices, prioritize resource management, and engage in research and development to address the issues the rice sector faces. These steps will not only increase output and productivity but also lessen the harmful effects that rice production has on the environment. Additionally, the review paper offers recommendations and insights for Ghana's transition to sustainable rice production practices, making it a useful resource for stakeholders, academics, and policymakers. To guarantee that sustainable solutions are successfully implemented, it asks for collaboration and coordination among all stakeholders.

Prospects for sustainable rice production in Ghana are bright, but they depend on coordinated action from a variety of stakeholders. Ghana can make substantial advancements in the following areas by adapting the following suggestions: (i) Protection of the environment thus using sustainable methods for rice production helps lessen the damaging effects of agriculture on the environment, such as soil erosion, water pollution, and greenhouse gas emissions. Ghana can encourage biodiversity, preserve natural resources, and lessen its ecological footprint by using techniques like conservation agriculture, integrated pest management, and efficient water use; (ii) Knowledge sharing and capacity building thus to spread knowledge about sustainable rice production methods, effective knowledge-sharing platforms, and capacity-building efforts are required. Farmers can be equipped with the skills and knowledge they need to embrace sustainable practices and increase their production and revenue through training programs, workshops, and farmer field schools; (iii) Support from policymakers thus setting up the right conditions for sustainable rice production is crucial. Creating and implementing helpful laws, rules, and incentives can motivate farmers to adopt sustainable practices, entice investment from the business sector, and guarantee the long-term viability of the rice industry; (iv) Research and development thus for Ghana's sustainable rice-producing methods to advance, research and development funding are essential. Innovations that solve the problems faced by the rice industry and maximize production efficiency might result from ongoing research on crop development, pest, and disease management, and agronomic practices unique to the local environment; (v) Socioeconomic development - the sustainable cultivation of rice has the potential to aid Ghana's socioeconomic growth. It can boost rural livelihoods, provide employment opportunities, and balance out income. Additionally, Ghana can boost its agricultural sector and increase food security by lowering its dependency on rice imports.

In conclusion, sustainable rice cultivation in Ghana is crucial for socio-economic development, food security, and environmental preservation. Ghana can overcome the difficulties facing its rice industry and pave the way for a more sustainable and prosperous future in rice production by putting a priority on sustainable practices, investing in research and innovation, and encouraging collaboration among stakeholders.

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